



## **Risø DTU Annual Report 2009**

Highlights from Risø National Laboratory for Sustainable Energy, DTU

**Pedersen, Birgit; Bindslev, Henrik**

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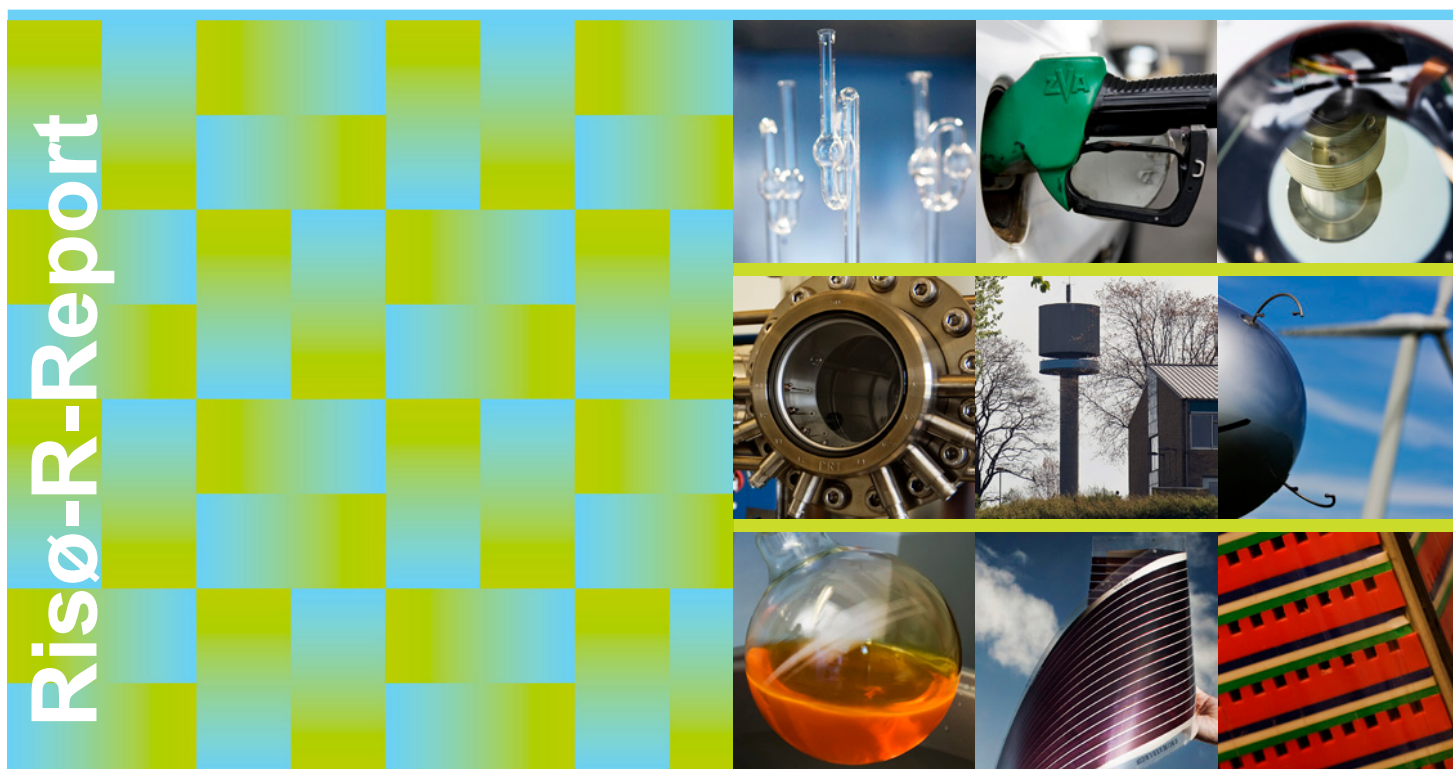
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# Risø DTU Annual Report 2009

Highlights from Risø National Laboratory for Sustainable Energy, DTU



Risø-R-1723(EN)

June 2010





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Edited by Birgit Pedersen and Henrik Bindslev  
Risø-R-1723(EN)  
Risø National Laboratory of Sustainable Energy  
Technical University of Denmark  
Roskilde, Denmark  
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*The avenue of poplars that is Risø's 'main street'. Like the rest of Risø's 262-hectare site, the avenue was laid out by the landscape architect C. Th. Sørensen in 1957 (Risø was inaugurated June 1958).*

Photos:  
Risø DTU unless otherwise stated.



# Risø DTU Annual Report 2009

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Edited by Birgit Pedersen and Henrik Bindslev

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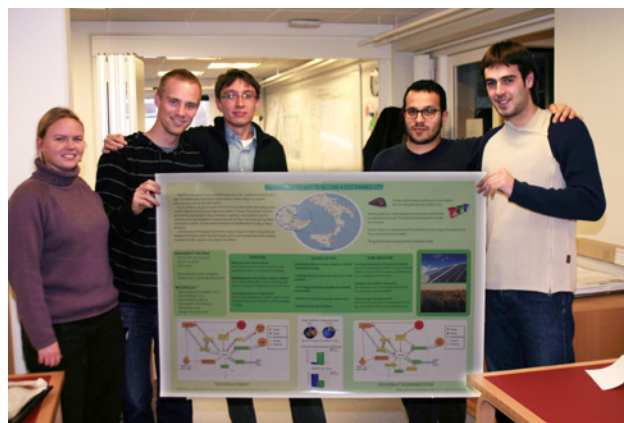
Grethe Winther successfully defends her DSc thesis on dislocation structures in metals and becomes the third female Doctor Technicus in Denmark, 29 May 2009.



Frederick C. Krebs receives the Carlsberg Energy Research Prize 09 in recognition of his research in polymer solar cells, 13 December 2009.



UN Secretary-General Mr. Ban Ki-Moon paid an official visit to Denmark on May 24-25. The Ministry for Foreign Affairs organized a boat trip to the off-shore wind farm "Middelgrunden". Risø's Director Henrik Bindlev was one of four invited to discuss Climate Solutions with the General Secretary.



The road to sustainability in various parts of the world is being discussed by the students at Risø's MSc programme in Sustainable Energy as they present their results from the course "Sustainability assessment of energy sources, conversion and use".



Risø demonstrates sustainable energy solutions at Roskilde Festival 28 June to 5 July 2009. The rock festival attracts 100.000 young people.



Centre leaders Dorte Juul Jensen, Risø, and Ke Lu, Institute of Metals Research (Shenyang) at the inauguration of the Danish-Chinese basic research centre on nano-metals, September 14.



## Preface

### **"Risø DTU contributes to research, development and international exploitation of sustainable energy technologies, and strengthens economic development in Denmark"**

The year 2009 saw unprecedented attention from media, populations and politicians on the issue of climate change and the momentous task of reducing green house gas emissions. It is now widely accepted that emissions associated with energy use need to be reduced dramatically with peaking of energy related emissions within a decade or so and deep reduction by mid century.

To bring about change affordably, sufficiently fast and on a massive scale calls for efficient research, development and deployment, which in turn calls for increased effectiveness in the cooperation among research, industry and policy makers.

This triple helix action we see on several fronts. The newly agreed test station for large wind turbines at Østerild, which will be run by Risø DTU, is one example which is paralleled by a burgeoning effort to unite research and industries in the endeavour to reduce price and increase reliability of off-shore wind power.

Similar efforts to unite across the development and deployment chain are seen in the field of smart grids. This field has attracted many new industrial actors in the recognition that here lie massive challenges and hence massive opportunities, the reaping of which require a broad palette of new competences.

In general the need to increase cooperation between research and industry, ensuring faster innovation, take up of knowledge and accelerated growth has received increased attention. It is with this aim that the Copenhagen Cleantech Cluster (CCC) was formed with Risø DTU as one of the founders. CCC today includes as partners the leading public and private clean tech enterprises active in Denmark.

Increased efficiency in research and development (R&D) calls for increased cooperation among research organizations across Europe and internationally. Aligning research programmes and reducing duplication increases the combined efficiency of the R&D effort. The European Energy Research Alliance (EERA) intends to deliver just that with



its Joint Programmes. At Risø DTU we are pleased to have been among the founders of EERA and count ourselves as a very committed EERA Partner.

The first four EERA joint programs (Wind, Solar PV, Smart Grids and Geothermal Power) with 45 participating research institutes were launched at the Strategic Energy Technology Plan conference June 2010. Including Joint Programmes in the preparatory phase, EERA presently counts more than 80 research institutes and thus represents an emerging European cooperation in energy research on an unprecedented scale.

The COP15 conference closed the year 2009 without the ambitious global agreement on green house gas reductions many had hoped for. While the climate agenda now is less present in the media the need for change is still massive and so are the opportunities to build new industries and secure new jobs.

A handwritten signature in blue ink, reading "Henrik Bindslev".

Henrik Bindslev  
Director







## Wind energy - a visionary match

Risø develops wind energy through research and innovation in key areas such as meteorology, wind turbine technology, offshore wind energy, power system integration and materials. In addition we are involved in test and measurements, standards and certification, and training.

### Measuring the wind flow over a MW wind turbine blade surface

Risø has concluded a large full-scale experiment on a 2MW wind turbine at Tjæreborg Enge on the west coast of Jutland, Denmark. The experiment included measurements



Every evening during the measurement campaign, all pressure taps, microphones and five hole pitot tubes on the test blade were covered with tape to protect against moisture and rain.

of more than 350 sensors, where a large part was built into a 38.8 m test blade. Four sections of the blade were measured in detail, and subsequently exact copies of those sections were made and tested in LM Glasfiber's wind tunnel. It was the first time that anybody carried out detailed measurements of the load distribution on a 40-metre-long blade under natural wind conditions, thereby providing an accurate picture of the wind flow over the wind turbine blade surface, and thus improving the basic knowledge on which impact the turbulence in the wind has on aerodynamics and aeroacoustics for a MW turbine. Better knowledge on this can contribute to tomorrow's turbines being more efficient and quieter, thus making it easier to

position turbines without affecting the neighbours of the wind turbines.

The DAN-AERO MW experiment succeeded thanks to pooling of the resources at Risø and the four other partners, Vestas and Siemens, the two largest wind turbine manufacturers in Denmark, and the blade manufacturer LM Glasfiber (now LM Wind Power) and the energy company DONG Energy.

### Representative wind measurements by means of wind lidar

With wind turbine tips reaching heights comparable to the Eifel tower, the meteorological towers used for measuring the wind and turbulence have also become progressively higher and thereby expensive to rise and install, in particular so in mountainous and complex terrain. With today's rotor planes in excess of 120 meters in diameter it is also evident that the winds representative for the inflow in the rotor plane are not any longer representatively measurable from a single cup anemometer installed at hub height.

Representative wind measurements require multi-point multi-height wind measurements within the entire rotor plane to accurately characterize the actual wind speed and wind shear in the rotor plane.

In 2009 Risø in particular addressed inflow wind condition measurements by use of our new measurement devices called wind lidars. Wind lidars are ground based or wind turbine integrated remote sensing devices, also called wind radars, which are able to measure the wind speed remotely at distances up to almost 1 km in front of the instrument.

#### WindScanner.dk

Research and technological development has begun addressing wind scanning within the entire rotor plane for

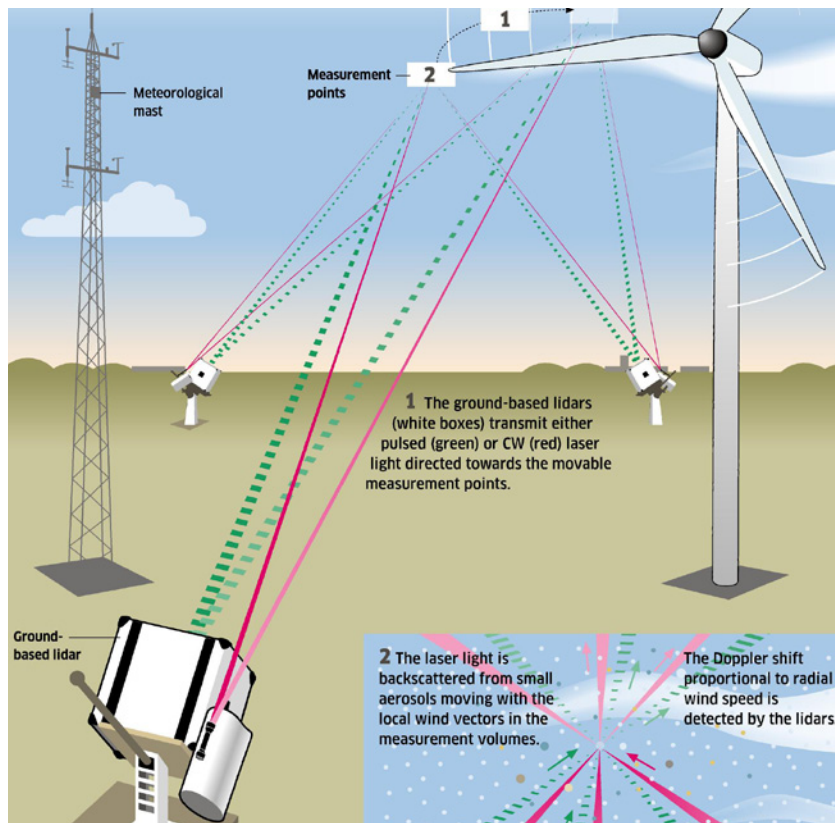
January 14

Workshop on Sustainable Energies, 14 - 15 January. The workshop is part of the DTU Climate Change Technologies Programme.

January 29

PhD student Kaspar Kirstein Nielsen receives the EliteForsk travelling scholarship from Denmark's Minister for Science, Technology and Innovation. The scholarship is used to visit the world's leading scientists in the field of magnetic refrigeration.





A spinner-mounted forward-looking wind lidar (a modified WindScanner.dk ZephIR) installed in the rotating spinner of a Vestas wind turbine NM80.

hub height wind turbine (Vestas NM80).

In collaboration with Natural Power and Malvern Instruments Ltd. we succeeded in operating a forward looking wind lidar with a conical scanner integrated into the spinner of an operating wind turbine. This concept allowed for an unimpeded view of the approaching wind field, which has been interrogated using several different scan patterns. Information on instant wind speed, shear and direction veer can be extracted and was compared to the output from an adjacent meteorological mast. The activity was done in collaboration with the DAN-AERO experiments performed simultaneously on the Tjæreborg test wind turbine during summer 2009.

*New mobile 3-D wind measuring system. The meteorological mast to the left only measures the wind vector at a few fixed points. A lidar-based WindScanner is, on the contrary, able to measure the wind field in the entire rotor plane of the wind turbine, via steerable scanheads.*

inflow and wake measurements. This is part of a new research infrastructure at Risø, WindScanner.dk, based on today's communication fibre-based wind lidar technology. The first set of three interconnected and coordinated wind-scanners with laser beam steerable scan heads have been designed and constructed, and laboratory testing with the first fully assembled WindScanner has begun.

#### *Wind turbines equipped with laser technology can predict the wind*

Risø has completed the world's first successful test on a wind turbine with a spinner-mounted forward-looking wind lidar, built into the spinner in order to increase wind turbine control and electricity generation. The results show that the integrated wind lidar can predict wind direction changes and warn against gusts of wind and turbulence. Risø therefore estimates that by using this laser system future wind turbines can increase energy production while reducing extreme loads.

During the 2009 Tjæreborg Enge Lidar-in-Spinner-Experiment, one of the three WindScanner lidars (a fast sampling continuous wave wind lidar, ZephIR) was modified and installed inside the rotating spinner of a large 80 m Ø, 59 m

#### *Commercial wind measurements with lidar*

The well equipped 120 meter tall meteorology mast at the Høvsøre Test Station has become an international benchmark for commercial lidar evaluation and calibration, and nowhere else in the world has there been verified as many lidar instruments as at Høvsøre. 2009 was the year when the global wind industry really began using lidar for wind measurements, and the year where lidar No. 100 came out.

#### **Flow modelling for wind energy: from global atmospheric data sets to microscale flow**

For many years Risø has developed methodologies for estimating wind resource at specific sites in order to provide a proper basis for decisions on where to place wind turbines. These methods comprise WAsP, the Wind Atlas Analysis and Application Programme. WAsP has been employed in about 110 countries and territories around the world, and has more than 2,600 registered users.

The methods build on modelling microscale effects such as obstacle, roughness and orography upon the local wind climate. The same methods can be used to generalize observed wind climates, so that measurements can be more properly applied at new sites.

#### March 17

Workshop on Transport - Renewable Energy in the Transport Sector and Planning, 17 - 18 March. Risø is the chair organizer. The workshop is part of the DTU Climate Change Technologies Programme.

#### March 19

At the European Wind Energy Conference (EWEC) Andreas Bechmann wins one of four poster prizes, and Rebecca Barthelmie receives the Academy Scientific Award.





In the absence of good quality measurements, mesoscale modelling has allowed wind resource calculation for large regions. With application of the mesoscale results in the microscale models even more valuable insight is gained allowing reliable wind resource estimates to be made at specific sites, using high resolution topography data.

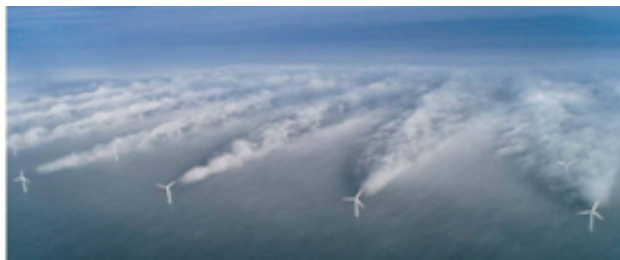
The beginning of the model chain is publicly available NCEP/NCAR Reanalysis data (200km). These data are used at Risø to drive mesoscale models (5 km) which in turn drive microscale models (1m).

The latest model chain developments have been primarily in *i)* ways to downscale with dynamical and statistical-dynamical methods in the mesoscale models KAMM and WRF, *ii)* ways to import more of the information from the mesoscale modelling to the microscale models, and *iii)* developing microscale models. A new linearized model with a better physics foundation and wake capability has been developed with the purpose of quickly calculating flow in complex terrain including wind farm drag, speed-up at hill tops, and flow angles (the latter becoming increasingly evident with the emergence of lidar measurements). Together with the fully non-linear models, Ellipsys3D and the canopy optimized SCADIS, and the linear models WAsP/WEng, a full suite of microscale models exists at Risø which can be applied to any terrain.

#### Turbulent flow fields in wind farms

The turbulent wind field in the wake of a wind turbine meanders, much like a pennant. In wind farms this gives rise to widely varying loads on downstream turbines. It is important to minimize and design to these loads, and that requires insight and reliable models.

Risø has recently developed a model based on fundamental physics. The model is based on the assumption that wakes can be described as successive releases of wake deficits whose stochastic motion (i.e. meanderings) in the flow field behind the wake-generating turbine is controlled by large-scale turbulence in the atmospheric boundary layer.



The model results in flow conditions with an intermittent nature, which has proved to provide heavy loads for downstream wind turbines. The model is verified both by using detailed full-scale lidar measurements (carried out by Risø) and by analysis of measurements made in a boundary layer wind tunnel (carried out by PRISME, Polytech'Orléans).

In contrast to the usual formulations of wake effects this theory provides the possibility to model both power performance and loading aspects, which allows a rational

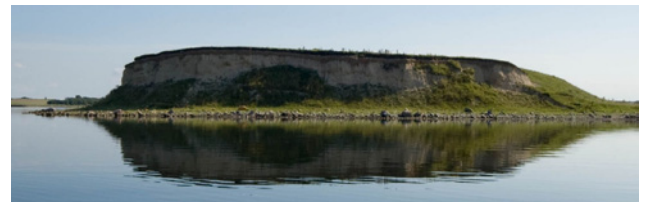
optimization of wind turbine farms. This is the theme of the European project TOPFARM, coordinated by Risø. The first - and highly simplified - version of this optimization platform has been developed, and examples of its performance were presented at the EUROMECH 508 Colloquium on Wind Turbine Wakes in Madrid late 2009.

The wake meanderings philosophy has recently been integrated into Risø's aeroelastic code HAWC2, and is being implemented at Vestas, Siemens, REpower and Garrad Hassan.

#### Wind turbines in complex terrain - the Bolund Blind Test

When erecting a wind turbine on hilly terrain, you initially need to determine the local wind conditions. For this purpose it is necessary to use both measurements and numerical tools, and in the Bolund experiment in 2007 and 2008 Risø made extensive measurements in order to obtain data to validate and improve such tools.

Bolund is a small island just north of Risø. During Risø's campaign in 2007 and 2008, velocity and high frequency



*The Bolund hill has a shape that is characteristic for many complex sites e.g. a well-exposed, almost vertical upstream escarpment. Also it has a well-defined inflow from the sea.*

turbulence data were collected simultaneously from 35 anemometers distributed on 10 masts, thereby generating a large database designed to validate CFD (Computational Fluid Dynamics) codes. The measurements were kept secret until a blind test was conducted in 2009.

In 2009 Risø challenged companies to predict the wind around Bolund. The challenge was taken by 40 companies and universities from around the world who all submitted their predictions. In December the submitted predictions (well over 50 model predictions) were presented and compared with the Bolund measurements. It took place at a workshop at Risø, and with more than 80 experts from around the world. During the two day workshop there were lively discussions, and while the RANS (Reynolds-Averaged Navier-Stokes) codes, including the Risø RANS code Ellipsys, performed the best, in the end the Bolund experiment itself turned out to be the "winner". The Bolund measurements now become an important element in future development of numerical tools.

#### Saving weight in tomorrow's wind turbine blades

Through intensive full-scale tests and advanced numerical calculations a significant potential has been found for weight savings in tomorrow's wind turbine blades. Risø has identified important mechanisms in how large wind turbine

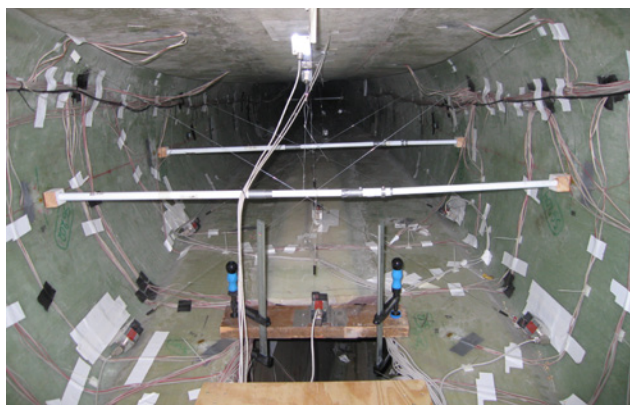


#### April 1

Risø joins Consortium on Digital Energy. CoDE is a new international consortium to map the shift to digital energy infrastructure (Smart Grids).

#### April 16

DTU Climate Centre at Risø is asked to advise the Danish Commission on Climate Change Policy. Furthermore, together with the Commission the Centre shall estimate the consequences of a Danish energy supply totally without fossil fuels.



*The blade in Risø's Experimental Research Facility for Blade Structure is equipped with numerous sensors inside.*

blades fail under extreme loads. This knowledge has made it possible to strengthen the weakest links and to reduce material consumption elsewhere in the blade. With a smarter internal structure of the wings, the quantity of material and the price can be reduced significantly.

Eight promising solutions/inventions have been found and are now patented. A systemic Proof of Concept phase is now conducted to demonstrate the impact of the new inventions in full-scale. This is done in Risø's Experimental Research Facility for Blade Structure.

#### **Improved wind farm performance by means of spinner anemometry**

It is a concern in wind energy that wind turbines do not yaw efficiently into the wind due to drawbacks of nacelle anemometry. The loss of power is estimated to be 1-3% in flat terrain and offshore, and up to 5% in complex terrain. Risø has developed an innovative concept, the spinner anemometer, which can determine the yaw error with very high accuracy. The first spinner anemometers have been tested successfully in several commercial wind turbines in Europe and on the other side of the globe. The spinner anemometer's potential for improving the energy output has been documented. Also, it was demonstrated that spinner anemometers improve verification methods of power performance in general.

Commercialization of the instrument continues, and a new project was started in 2009, where the objective is to implement spinner anemometers in a whole range of turbines in Horns Rev I offshore wind farm together with among others Vattenfall.

#### **Intelligent wind turbine blades inspired by nature - adaptive trailing edge of flap**

On a hot windy summer day the air is full of turbulence. In these unsteady surroundings a bird of prey is hovering, completely still, with the eyes focused on its prey in the field. The bird does this by adapting its wing shape to the constantly changing turbulence.

This inspired researchers at Risø to think: If we could adapt the same intelligence to a wind turbine, i.e. manage to

adapt the shape of the blades while harvesting the power of the turbulent wind, we could reduce the load on the turbine structure. Three things were identified to be needed to succeed: It should be possible to detect the wind in details, choose an intelligent response, and rapidly adapt the blades.

Adapting the blade was done by means of a flap on the trailing edge of the blade. Such a flap can be compared to the large feathers on the bird's wing, or to the aileron-flap on an airplane wing. The flap gives the wing the ability to respond to the turbulence. Airplanes have fixed flaps that can be lowered, but such flaps make noise and destroy the relation between lift and resistance.

Instead Risø wanted to develop a wind turbine blade where the whole rear edge had been made flexible. This was done by adjusting the blade edge by piezoelectrical actuators that are light and react quickly.

By adding sensors that detect the wind, a computer determines the optimal position of the flaps. The control algorithm ensures that the blade edge deforms the right way; quickly because the wind changes every second and the system needs to keep up.

The first ever full-scale tests on a wing with an adaptive trailing edge flap was conducted late 2009 on the Vestas V-27 turbine at Risø.

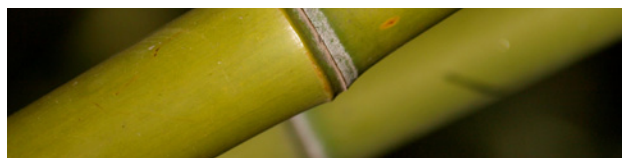
#### **Critical delamination of composite materials for blades**

Wind turbine blades are often manufactured of composite materials in a layered structure. In the manufacturing process there might be areas where there is poor or absent adhesion between 2 layers. This is called delamination, and it degrades the strength of the composite structure.

Risø therefore seeks to find new methods for determining the criticality of delamination of composite materials in the layered structure. Based on numerical analysis and experimental test Risø has developed maps showing expected buckling characteristics and reduced compressive strength as a function of size of the delamination and the position in the depth of the laminate. These maps can be used as a tool to assess whether an observed delaminating of multi-layers is critical and must be repaired.

#### **Bamboo - a sustainable material for wind turbine blades**

With support from Siemens Wind Power, and in collaboration with the Bamboo and Rattan Institute in Beijing, Risø has started a new effort using bamboo material for small to medium scale wind turbines. Bamboo is a very interesting material for this purpose as it is natural, it grows fast, the fibres are very well aligned, and by 'forming' the bamboo into 'plywood' composites very good mechanical properties are obtained.



Colourbox

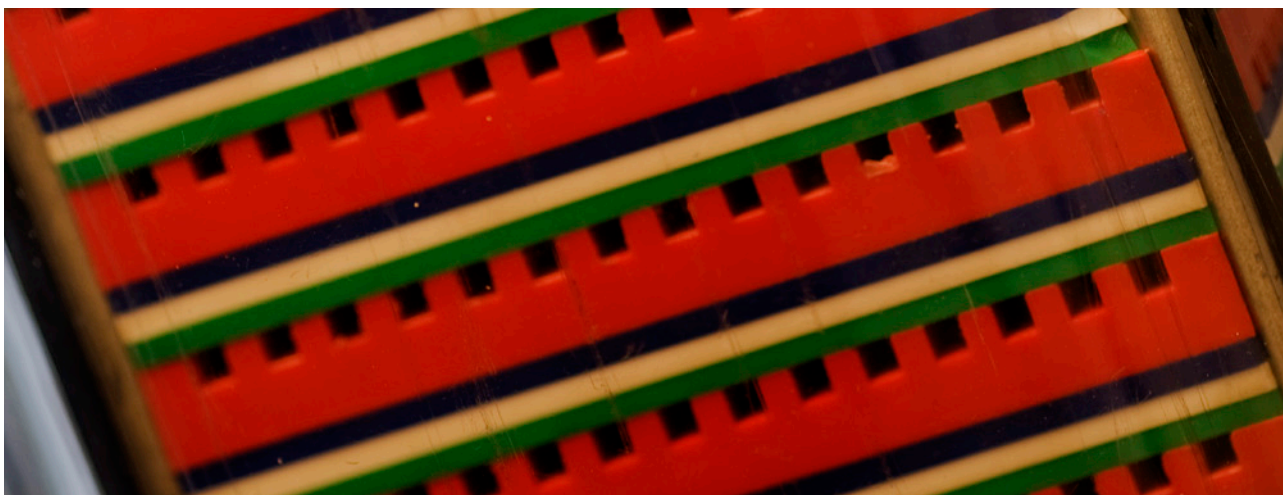
#### **April 16**

Risø holds the workshop "Control and Demand Side System Services in Systems with Large Scale Wind Power". It is the first workshop in a series to present the challenges faced when dealing with a larger amount of wind energy in power systems.

#### **April 17**

As the first in the world Risø connects a polymer solar cell plant to the grid. This is the result of extensive research into polymer solar cells as a cheap alternative to existing silicon-based solar cells.





## Fuel cells & hydrogen - part of the flexible and efficient energy system

With fuel cells capable of producing energy from hydrogen and other fuels, we have taken a major step forward towards the goal of sustainable energy production. This will have a positive effect on the global environment because it contributes to a reduction of CO<sub>2</sub> emissions and preserves natural resources.

Risø's research into fuel cells and hydrogen contributes to this development. Among other things, we are supplying the basic knowledge for Denmark's production of SOFC fuel cells.

### Development of efficient and durable solid oxide fuel cells

Risø is developing efficient and durable solid oxide fuel cells. A fuel cell converts chemical energy to electricity with high efficiency. The heart of the cells are based on ceramic layers with specific functions, such as pure ionic conductivity and gas tightness, porous and catalytic active electrodes. Stacks of cells are built to obtain the required voltages and power ranges.

The research and development of solid oxide fuel cells have now reached the so-called 2.5 and third generations, where the former is an advanced anode-supported cell while the latter is a cell built on top of a porous metal support.

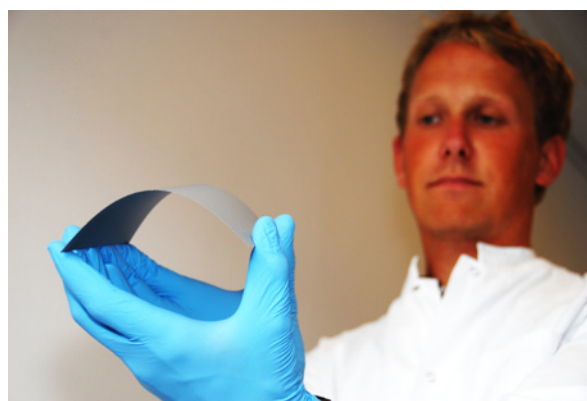
The next-generation solid oxide fuel cells ("3G") have been tested for the first time in full size (12 x 12 cm<sup>2</sup>) in a stack for 100 hours. Such cells - which have a support layer of metal instead of ceramics - are cheaper and mechanically stronger than the standard cells. The results of the test were very encouraging and show the feasibility of the concept. The cells will undergo additional development in projects together with Topsoe Fuel Cell A/S.

On April 28 2009 a Topsoe Fuel Cell pilot facility for the production of solid oxide fuel cells and stacks was inaugurated in the presence of Haldor Topsøe and the Danish minister for Economic and Business Affairs. The pilot facility is based on Risø know-how and R&D. This technology transfer marks an important point in the longstanding co-operation between Risø and Topsoe Fuel Cell and will lead to the building of a full-scale plant within the coming years.

### Solid oxide electrolysis cells and synthetic fuels

In a society based mainly on renewable energy, storage and transport of this energy from the point of production to the point of consumption will play an important role. The main reason for this is that wind and solar energy production cannot be turned on and off at will. It is necessary to convert surplus electricity from e.g. wind power to chemical energy in the form of compounds such as hydrogen, methane or methanol. In this form the energy is easy to store and use in for instance vehicles.

Electrolysis is an attractive technology for this energy conversion. By electrolyzing water, splitting it into hydrogen and oxygen, electrolysis cells convert electricity to chemical energy.



*Despite being made of ceramic materials 3G fuel cells are very flexible.*

April 25

Risø participates in the yearly Festival of Research. The Festival of Research is an annual national event intended to arouse public interest in and enhance public understanding of the methods, processes, and outcome of research and science.

April 27

Risø holds "Offshore Wind Energy: Technical Course" 27 - 30 April with lectures/tuition in various aspects of offshore wind energy in pre-planning, planning, and operational stages.





At Risø we are developing electrolysis cells based on our extensive competences within solid oxide fuel cells. The electrolysis cells operate at high temperature, giving them a very high efficiency. Furthermore they will also be able to produce syngas, i.e. a mixture of hydrogen and carbon monoxide, which can easily be transformed into liquid synthetic fuels, such as synthetic petrol. Initial tests have already shown the promise of the cells developed at Risø.

### Electrochemical gas purification

There is an increasing focus on reducing exhaust emissions. Solutions exist for cleaning the exhaust gasses from most stationary systems and from ordinary internal combustion engines. However, there are still unsolved problems in connection with Diesel engines and lean-burn engines, especially with regard to the burning of soot and removal of  $\text{NO}_x$ .

Electrochemical cells of the solid oxide type can be used to clean flue gasses (exhaust gasses) of soot particles and nitrogen oxides.

Risø's work on electrochemical gas purification is focused on developing electrodes which are active for the oxidation of soot and active/selective for the reduction of  $\text{NO}_x$  in an oxidizing atmosphere. The Danish company Dinex Emission

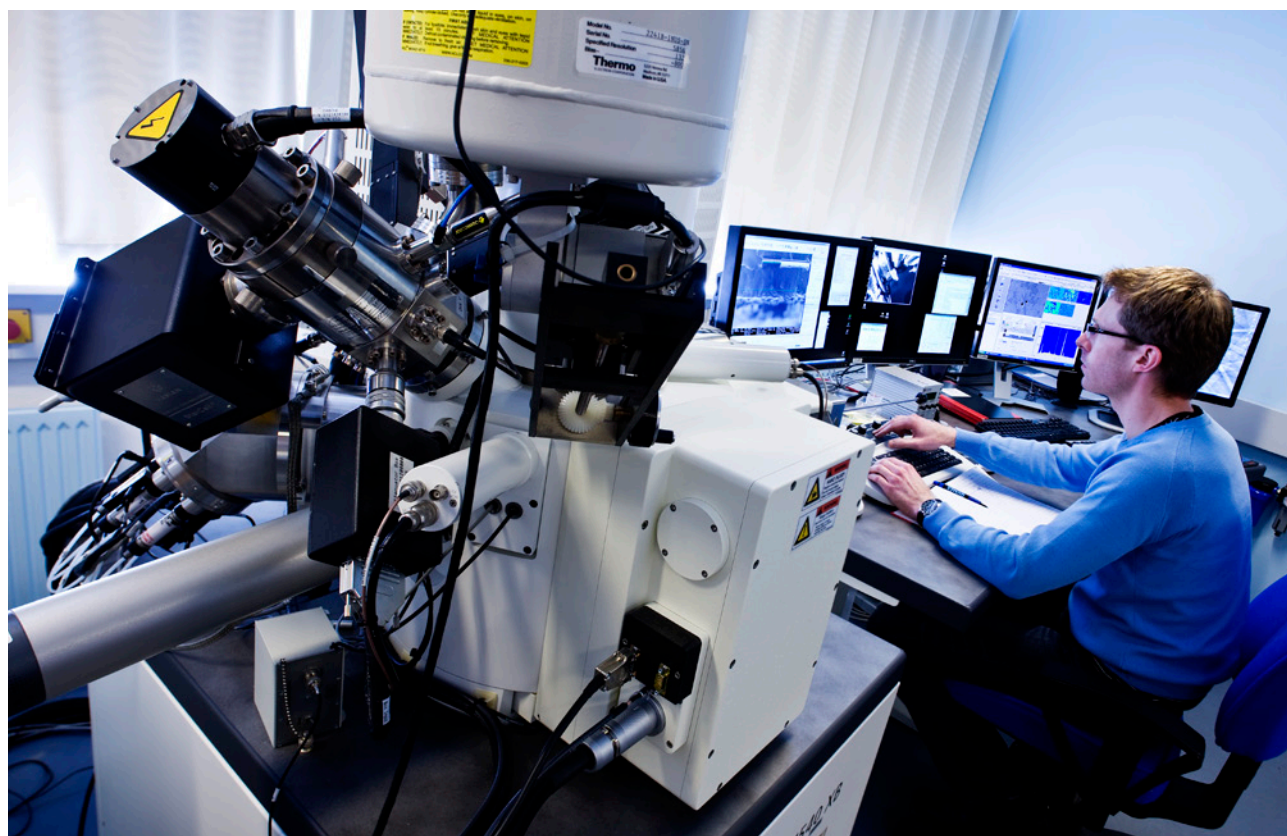
Technology A/S is a partner in a project on development of new and better electrode materials, modeling and manufacturing of prototype filter units and the testing of filters under realistic conditions.

### Magnetic materials used to create cooling and heating

Magnetic refrigeration is a new and exciting technology that can be used to create low noise energyefficient cooling with environmentally friendly materials. Risø is working on creating a new prototype of a magnetic refrigeration device, which will hopefully be finished within the coming years.

Traditionally cooling is made by the use of compressors, - this is the noise one hears from the refrigerator or freezer. Risø is developing a very different concept, magnetic refrigeration, where magnetic materials are used to create cooling and heating.

The system takes advantage of the so-called magneto-caloric effect, which means that a magnetic material under certain conditions will heat when exposed to a magnetic field, and heat-up when the magnetic field is removed again. In a research project, Risø has designed a rotating magnetic system, which is to be the prototype demonstrating the concept at around room temperature.



A scanning electron microscope equipped with an ion beam source which can be used for cutting materials, a so-called focused ion beam. By means of 3D-reconstruction the granular structures in solid oxide fuel cells are mapped by cutting them up with the ion beam and reconstruct the microstructures by means of Risø's newly developed algorithms for 3D image analysis.

April 28

A Topsoe Fuel Cell pilot facility for the production of solid oxide fuel cells and stacks is inaugurated in the presence of Haldor Topsøe and the Danish minister for Economic and Business Affairs. The pilot facility is based on Risø know-how and R&D.

May 5

The UNEP Risoe Centre and the Ministry of Foreign Affairs of Denmark holds the seminar "Finance and Technology Needs to Address the Climate Challenges". The seminar addresses climate problems in developing countries.







## Bioenergy - a precious, renewable energy source

Biomass is organic matter created through plant photosynthesis with the sun as energy source, i.e. all types of plant material, wood, manure, household waste etc.

Plant biomass can be used both for food for humans, feed for animals and for energy in the form of heat, electricity, gas and liquid fuel. Energy production based on biomass can offer significant environmental benefits by substituting fossil fuels and thus reduce the increase in atmospheric greenhouse gases, particularly CO<sub>2</sub>, and it can contribute to enhanced security of supply.

Risø conducts research in technologies for converting biomass into biofuels and biomaterials.

### From laboratory scale to demonstration: The world largest 2G bioethanol inaugurated

On November 18th 2009 Inbicon (a subsidiary of DONG Energy) inaugurated the 2G bioethanol demonstration plant in Kalundborg, Denmark. The plant will annually produce 5,4 million litres of ethanol, 13.000 tons lignin bio pellets and 11.100 tons C5-molasses per year on the basis of 30.000

tons of wheat straw as raw material, i.e. 4000 kg straw per hour. The bio pellets can be used as fuel at Combined Heat and Power (CHP) plants, and the C5 molasses can be used for animal feed and other purposes. Thus, all elements in the biomass are being utilized.

This was a major event for Risø where the very first Danish research of the pre-treatment technique was carried out



At Kalundborg port, the new Inbicon Biomass Refinery is integrated with the adjacent coal-fired Asnæs Power Station, owned by DONG Energy. Risø has participated in the development of the pre-treatment process.

#### May 12

Workshop on Climate Changes and Ecosystem Productivity, 12 – 13 May. The workshop is organized by Risø DTU and DTU AQUA and is part of the DTU Climate Change Technologies Programme.

#### May 29

Grethe Winther successfully defends her DSc thesis on dislocation structures in metals and becomes the third female Doctor Technicus in Denmark.





in 1990. In 2002, Risø and DONG Energy became partners in an EU project on development of hydrothermal pretreatment of wheat straw in pilot scale for ethanol production. The goal of the project was to construct a 100 kg/hour pilot scale reactor for conversion of straw to a substrate for ethanol producing microbes. A 10kg/hour reactor developed at Risø was the model for the pilot reactor. With assistance of experienced engineers from Dong Energy the goal was achieved. Following further upscaling by DONG Energy this finally led to the construction of the Inbicon demonstration plant.

The 10 kg/hour reactor is still used for research purposes at Risø where further improvement of pre-treatment of organic materials for production of 2G bioethanol is an important research topic.

#### Low temperature circulating fluid bed gasification

During the last years a novel gasification process has been developed, Low Temperature Circulating Fluid Bed Gasification (LT-CFB). The process is able to gasify all types of dry organic matter regardless the amount and composition of ash components.

The process operates at a temperature which is low enough to avoid ash sintering (below 730°C). The produced gas has a high content of tar, but a very limited content of ash since the ash is retained in the gasifier. This means that the gas is suitable for burning in a power plant boiler replacing coal. In these boilers it is of great value that no biomass ashes are introduced, because the ashes cause

problems with corrosion and deposits.

The process was originally invented by Danish Fluid Bed Technology ApS (DFBT) during a collaboration project with DTU. The technology was developed in collaboration between DTU, DONG, Anhydro, Force and DFBT.

DONG has decided to use this technology as part of their strategy away from fossil fuels, and has started up a scaling project with a budget of around 100 mill DKK.

#### Significant amounts of nitrous oxide from organic plant production

Besides being a potent greenhouse gas, nitrous oxide (laughing gas) has been identified as the dominant ozone-depleting substance emitted in the 21st century. Research performed at Risø (CROPSYS and BioConcens projects) shows that, on an area basis, organically and conventionally managed winter wheat fields emit comparable amounts of  $N_2O$  despite a lower N-input to the organic system.

A challenge in organic farming is to make the organically bound nitrogen available for the plants when they need it, which could potentially reduce the  $N_2O$  emissions. One option is to decompose animal manure and crop residues in a biogas plant before the materials are used as fertilizer in the field. However, our work suggests that significant emissions of  $N_2O$  occur after field application of biogas wastes (anaerobic digested cattle slurry) to an extent that potentially offsets the positive greenhouse gas balance obtained by using the produced plant material for energy purposes.



Low Temperature Circulating Fluid Bed Gasification test facility at DTU. The process operates at a temperature which is low enough to avoid ash sintering (below 730°C).



A challenge in organic farming is to make the organically bound nitrogen available for the plants when they need it, which could potentially reduce the  $N_2O$  emissions.

#### June 8

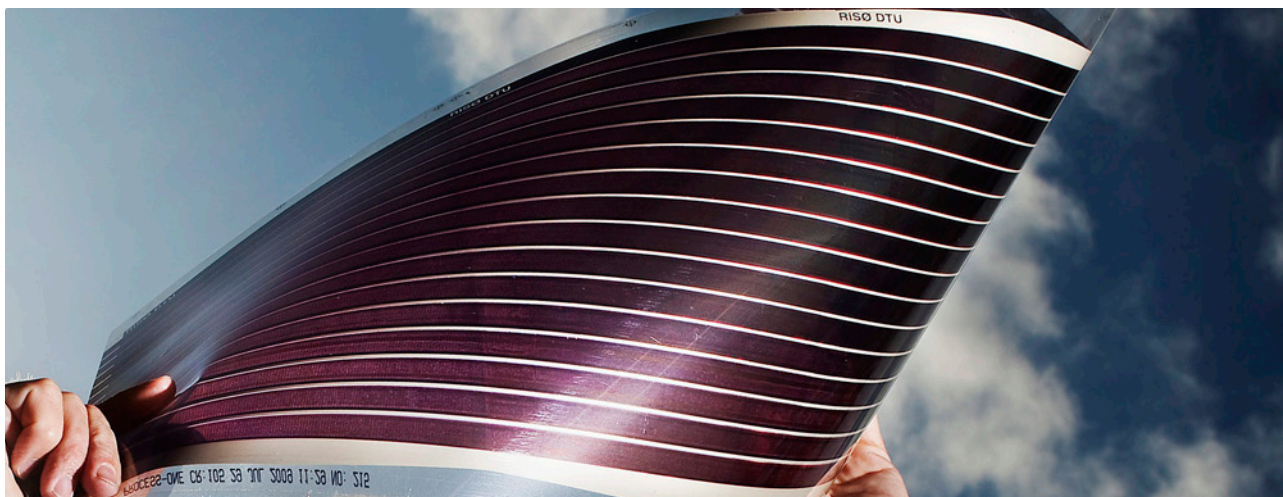
Risø holds a PhD Summer School on "Remote sensing for wind energy" 8–11 June. 27 participants, 10 nationalities, people from industry and PhD students from various technical universities.

#### June 24

UNEP Risø Centre is one of the organizers of the Latin American and Caribbean Forum 2009, Panama, 24–26 June. 500 people meet to discuss the global and regional carbon market.







## Solar energy - by far the most abundant source of energy

Solar energy technologies directly convert sunlight into electricity and heat, or the sunlight powers chemical reactions that convert simple molecules into synthetic chemicals and fuels. The sun is by far the most abundant source of energy, and a sustainable society will need to rely on solar energy as one of its major energy sources.

Risø carries out research on future generations of photovoltaic technologies (PV) and in particular polymer solar cells - a most likely candidate for ultra-low cost solar cells in the future. The research effort covers the full range from new materials, test methods and research on stability and structure to processing and demonstrations.

### Polymer solar cells connected to the grid

As the first in the world Risø in 2009 connected polymer solar cell panels to the grid. The demonstration at Risø was the result of an extensive research into polymer solar cells.

The polymer solar cells for the solar cell plant were produced in collaboration with Mekoprint A/S, who specializes in "roll to roll" production of flex-print and printed electronics. After the production of the solar cells - and in collaboration with Gaia Solar A/S - Risø manufactured the large panels upon which the solar cells were mounted. Gaia Solar A/S specializes in module construction of silicon solar cell panels and has built Risø's polymer solar cells into their design. The panels are placed on a solar tracker which follows the movement of the sun and the generated power is added to the grid.

Already in June 2008, Risø presented the polymer solar cells at the Roskilde Festival in cooperation with Mekoprint A/S. At that time the price was 4.500 € / W, but a huge effort in raising the efficiency made the price go down to 22 €/W in January 2009 and further down to 15 €/W in March 2009. By the end of 2009 the price was again halved at which time the efficiency was increased to more than 2%. Collaboration with the industry seeks to promote the industrialization of polymer solar cells in Denmark and if this succeeds, polymer solar cells can become a ground-breaking energy technology to be used in Denmark and also for export.

### Polymer solar cells to provide reading light for school children in developing countries

In 2009 Risø's research and development in polymer solar cells reached a stage where Risø could start working to

demonstrate possible applications of polymer solar cells, and an exciting innovation and aid project was initiated. Risø was awarded a grant by Region Zealand to demonstrate the idea of a polymer solar cell lamp based on a rechargeable battery and a LED light source as an alternative to the polluting and unhealthy kerosene lamps that are widely applied in developing countries. The project was called "Lighting Africa", a title borrowed from the program collaboration between the International Finance Corporation (IFC) and the International Bank for Rebuilding and Development (IBRD), also known as the World Bank.

The polymer solar cell lamp is a prototype intended as a reading light for school children, and the lamp gives sufficient light to read at night. The sheet of polymer solar cells constitutes both the 'foot' and the screen of the lamp.

Prototypes of the polymer solar lamp were tested in Zambia by students at the Copenhagen Business School, and the test proved that the concept is functional. The lamps have the ability to be cheaper than the existing high quality

and high cost lamps and qualitatively better than the cheaper low quality solar lamps. With further product development Risø's polymer solar cell lamp can be established as a commercial product.



"Lighting Africa" lamps based on polymer solar cells.

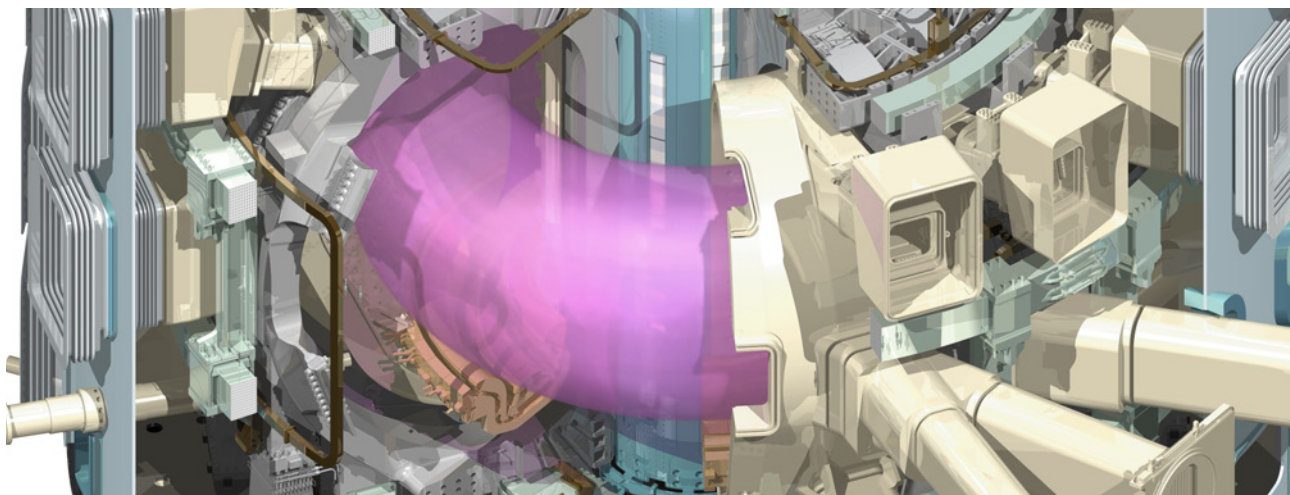
#### June 28

Risø demonstrates sustainable energy solutions at Roskilde Festival 28 June to 5 July. The rock festival attracts 100.000 young people.

#### Summer

Together with designers Risø demonstrates 3D forming of biocomposites. The work is exhibited at the Tapholt Museum during the summer and is awarded by The Danish Arts Foundation for sustainable thinking of the textile's possibilities.





## Fusion energy - tomorrow's inexhaustible energy source

Fusion energy powers our sun and the stars, and is released when light elements as for example deuterium and tritium fuse together.

Worldwide coordinated fusion research started in the late 1950s to find ways to use fusion as an energy source here on Earth. Risø has participated in fusion research since its very beginning, and the effort is an integrated part of the European program through Euratom. This includes participation in the European fusion experiments, as e.g. JET (Joint European Torus), and contributions to the ITER, a large-scale international scientific experiment that aims to demonstrate that it is possible to produce surplus of energy from fusion.

Fusion energy is a safe form of nuclear energy, which does not pollute the atmosphere with CO<sub>2</sub> and other greenhouse gases. The fundamental "fuels" deuterium and tritium are practically inexhaustible. Deuterium is found abundantly in seawater, and tritium will be produced in the fusion power plant from lithium that is abundant in the crust of the earth. Power plants become radioactive, but the radioactivity will be gone after 100 years, and there will therefore be no need for long-term storage of waste.

### Identification of propagating current filaments in magnetized plasmas

Edge localized modes (ELMs) can have a considerable influence on fusion plasma performance. The ELM phenomena is a short and sudden loss of plasma from a fusion device, which can put excessive heat loads on the plasma facing material components and therefore needs to be controlled without losing the plasma confinement.

Magnetic probe measurements at the JET and AUG fusion experiments have shown that so-called ELM filaments carry a significant amount of current. A specific probe was constructed for AUG (ASDEX Upgrade, tokamak at Max-Planck-Institut für Plasmaphysik, Garching, Munich) showing that the current is localized in the filaments. These new results add significantly to our understanding of the ELM phenomena.

Cooperation throughout the European Fusion Development Agreement (EFDA) made the measurements possible.

### Determining the fuel ion ratios in fusion plasmas

The determination of the fuel isotope ratio in ITER is a matter of concern. In 2009 Risø was the lead partner in an international effort to develop novel methods to determine this. Risø demonstrated that the fast ion CTS diagnostic system on TEXTOR (Torus Experiment for Technology Oriented Research) could also be used to measure ion Bernstein waves and in turn determine the fuel ion ratio.

CTS (Collective Thomson Scattering) is a relatively new technique for measuring fast ions in fusion plasmas. Since 2001, the development of CTS have been managed and operated by the fusion research group at Risø, and Risø also designed a system for ITER.

### CTS measurements of fast ion distribution function

Fast ions, which in a fusion plasma also includes fusion products such as alpha particles, are essential for the heating of the plasma. But at the same time they provide a considerable source of free energy that may destabilize the plasma. The dynamics of fast ion will be one of the central research objectives in the ITER experiment.

A very promising system based on CTS by millimetre waves has been developed at Risø, and in 2009 the Risø CTS team made the first measurements of the fast ion distribution function on ASDEX Upgrade and made direct comparison to TRANSP/NUBEAM calculations.

### Fusion energy and Big Science

Risø has - in collaboration with the Danish Technological Institute and FORCE Technology - been awarded a Big Science Secretariat to strengthen Danish companies' acquisition of exciting contracts from ITER, ESS (European Spallation Source), XFEL (European X-Ray Laser Project) and other Big Science projects. The secretariat is based on the ITER Industry Network which Risø has built and run a number of years, and it will be located at Risø.

August 31

Risø welcomes 35 students to the MSc programme in sustainable energy.

September 7

30th Risø International Symposium on Materials, 7 - 11 September. The theme is "Nanostructured metals - Fundamentals to applications".







Colourbox

## Climate and energy systems - sustainable and reliable global energy supply

Globally, three central challenges for the energy systems of the future are emerging: A need for strengthening the security of supply, ensuring reduced emissions of greenhouse gasses so that we can halt climate change, and solutions which contribute to fighting poverty.

Risø contributes to solving these challenges by

- research in and analysis of energy systems and opportunities to support increased integration of wind power and other fluctuating energy sources in the energy network, and
- research into energy policies and energy systems with particular focus on environmental and climatic consequences, including in the developing countries.

### **SYSLAB - further development of the research facility for intelligent energy systems**

With a vision of 100% independence of fossil fuels, the electricity system needs to be rethought so that this becomes possible. Today the consumption dictates how much electricity is produced. In the intelligent energy system (Smart Grids) the production controls the consumption. When the wind blows or the sun shines, consumption will automatically be adjusted, and consumption and consumers

will go from being passive participants to be active players in the electricity system. However, not in a way so that the individual must take a lot of complicated decisions, but through a series of automated technologies that seamlessly in the background serves as a part of everyday life.

The management of the current energy system is based on large power plants which ensure stable voltage and frequency regardless of the level of consumption. In a future electricity system the stabilizing functions will be based on



A rebuilt Toyota Prius plug-in hybrid car is connected to the local SYSLAB grid by Jørgen Christensen, Danish Energy Association, one of the partners of a electrical vehicle project called EDISON.



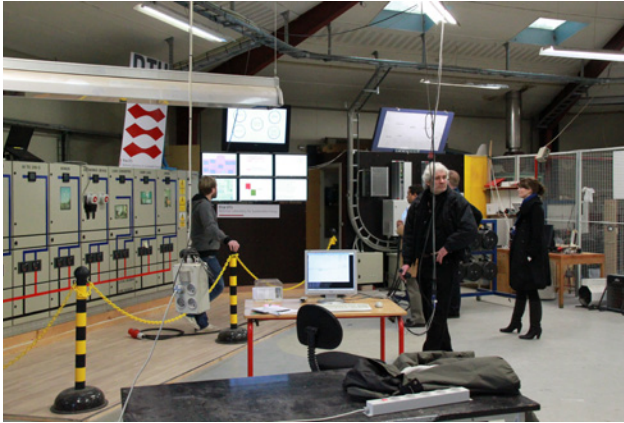
#### September 7

40th course on "Validation and Process Control for Electron Beam Sterilization", 7 - 11 September. The first course was held in 1993. The courses are aimed at industrial users of e.g. medical equipment, and at authorities.

#### September 7

Around a dozen small and medium-sized enterprises participate in Risø's innovation network "Future energy technologies" where SMEs are brought together with Risø scientists.





*The control room in SYSLAB is presented to a delegation of international journalist visiting Risø in the time up to COP15.*

intelligent communications and interactions between many large and small entities in the network.

SYSLAB is a flexible platform for research in advanced control systems and concepts, power system communication and component technologies for distributed power systems. The SYSLAB facility is spread across multiple locations at Risø. Its backbone is formed by a 400V grid with several busbars and substations. A central crossbar switch with tap-changing transformers enables meshed operation and power flow control.

All units on the grid – generators, loads, storage systems, switchgear – are automatised and remote-controllable. Each unit is supervised locally by a dedicated controller node. The node design combines an industrial pc, data storage, measurement and I/O interfaces, backup power and an Ethernet switch inside a compact, portable container. All nodes are interconnected via redundant highspeed Ethernet, in a flexible setup permitting on-line changes of topology and the simulation of communication faults.

In 2009 a new version of the SYSLAB software infra-

structure was implemented. The new version has enabled the implementation of various communication interfaces to each of the components of SYSLAB, e.g. the standard SCADA (Supervisory Control And Data Acquisition), IEC 61850 communication and function-/ancillary service-based communications. In addition, radio frequency based component identification (RFID) and GeoCan algorithm to determine geographic proximity to allow for self-organized management that takes into account topology has been established.

#### **Risø FlexHouse - live experiment on active load management**

Risø FlexHouse is a small office building which has been converted into a live experiment on active load management in order to explore the technical potential for actively controlled buildings in intelligent power grids. Unlike most other buildings at Risø, its energy supply is purely electrical. With a peak load of around 20kW, the building is well-sized for parallel operation on the SYSLAB power grid.

A controller and the infrastructure for data acquisition and management of the FlexHouse have been established, and a controller has been implemented that controls the room temperature in individual rooms depending on user preferences as well as on wind energy production in the power system. The facility is used in several projects, developing algorithms for optimal control and operation.

#### **Assessment of wind turbines' impact on the grid**

For the evaluation of wind turbines' impact on the grid, the wind turbine supplier are to provide validated models that can be used to simulate the wind turbine and the power system. Risø has been given the Convener role of the IEC standard working group "IEC61400-27 Electrical simulation models for wind power generation". First meeting took place at Risø and work on standard models of the industry's most commonly used wind turbine concepts was launched.



*Risø's FlexHouse is a live experiment on active load management in order to explore the technical potential for actively controlled buildings in intelligent power grids. To the right is the solar panel which is a part of the SYSLAB.*

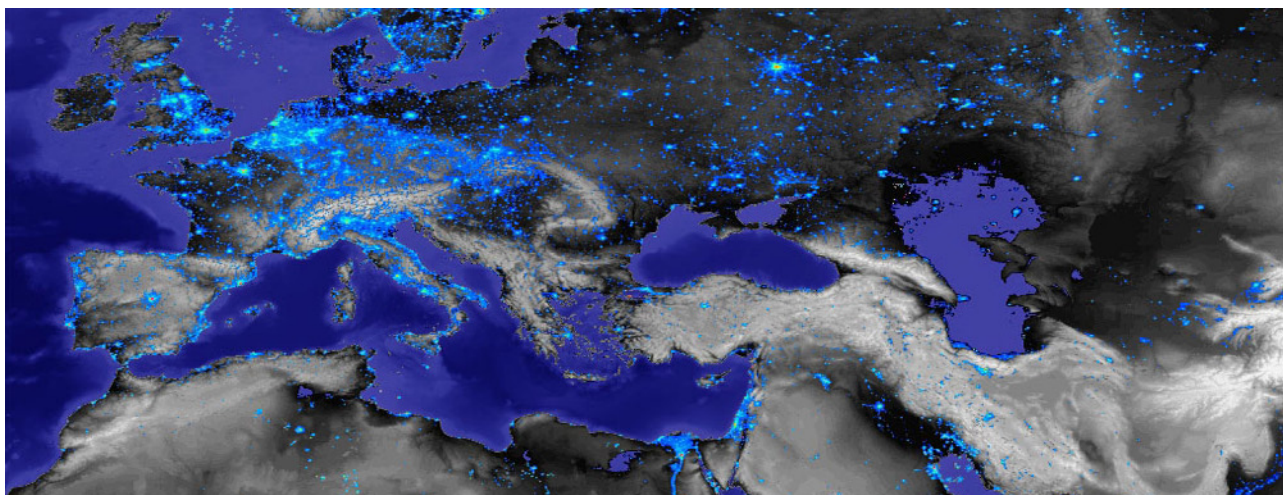
#### **September 9**

Official launching of Copenhagen Cleantech Cluster. CCC is established on the initiative of Risø DTU, Scion DTU, Copenhagen Capacity, The Confederation of Danish Industry and University of Copenhagen.

#### **September 14**

Risø inaugurates a Danish-Chinese basic research centre on nano-metals. Chinese partners are Institute of Metals Research (Shenyang) and the universities Tsinghua and Chongqing. The center is established with funding from the Danish National Research Foundation.





### DTU Climate Centre at Risø

During 2009 the DTU Climate Centre at Risø has been fully established and staffed, and a number of interdisciplinary research projects have been initiated.

It is one of the objectives of the Centre to advise the public and private sectors in the area of climate, and in 2009 the Centre, together with the consultancy company EA Energy Analysis, was selected by the Danish Commission on Climate Change Policy to analyze the technical solutions and socio economic costs for realizing the vision of 100% independence from fossil fuels.

Furthermore, the Centre, together with the meteorological institute DMI, became part of the "Centre for Regional change in Earth System (CRES)", a new Danish climate research centre. One of the tasks will be to develop a new and more detailed regional climate model to be used for making decisions on climate adaptation in Denmark. There is a lack of climate models that can predict the development at a detailed regional level, and the climate model is to prepare Denmark for climate change and to reduce uncertainties in future planning.

### Launching of Technology Needs Assessment programme

The UNEP Risø Centre (URC) supports the United Nations Environment Programme (UNEP) in its aim to incorporate environmental aspects into energy planning and policy worldwide, with a special emphasis to assist developing countries.

In October 2009, UNEP and the UNEP Risø Centre on Energy, Climate and Sustainable Development were given the go-ahead to launch a vast Technology Needs Assessment (TNA) programme, funded by the Global Environmental Facility (GEF). The programme will help define what kind of clean technologies are best suited for individual countries and what is the best way to get them up and running. The programme will not only help country partners identify their technology needs regarding climate change mitigation and adaptation, but also help them develop Technology Action Plans (TAPs) designed to enable and facilitate



*The Technology Needs Assessment (TNA) programme launched by UNEP and UNEP Risø Centre covers 15 countries, among others Thailand.*

the smooth transfer of the selected technologies.

The first round of the project began in November 2009 in fifteen countries: Kenya, Senegal, Cote d'Ivoire, Morocco, Mali, Argentina, Costa Rica, Peru, Guatemala, Bangladesh, Thailand, Vietnam, Indonesia, Cambodia, and Georgia.

### Evaluation of future climate conditions on plants

At Risø Environmental Risk Assessment Facility (RERAF), a unique climate phytotron, the effects of future climatic conditions on plants are evaluated. Plant production is evaluated and so is the adaptability to fast climate changes.

Two model species, the crops barley (*Hordeum vulgare*) and oilseed rape (*Brassica napus*), have been exposed to different combinations of elevated CO<sub>2</sub>, O<sub>3</sub> and higher temperatures for four and five generations, respectively.

The plants were cultivated in multiple and single factor treatments of CO<sub>2</sub>, O<sub>3</sub> and temperature, and the watering was controlled simultaneously. Plant production, despite being variety-dependent, responded positively to higher CO<sub>2</sub>-concentrations and negatively to higher temperatures. However, due to the opposing effects of CO<sub>2</sub>-concentrations and temperature in treatments applying several factors simultaneously, the production did not change significantly from ambient conditions. Ozone at the level applied

September 14

Risø International Energy Conference 2009 takes place 14 - 16 September. This year's conference deal with energy solutions that can reduce global CO<sub>2</sub> emissions.

September 14

International Workshop on Small Scale Wind Energy for Developing Countries, Kenya, 14 - 16 September. Organizers are Risø DTU and Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya.







At Risø Environmental Risk Assessment Facility (RERAF), a unique climate phytotron, the effects of future climatic conditions on plants are evaluated.

here did not have significant effects on the production. It has been predicted (e.g. IPCC, 2007) that the agricultural production in southern Scandinavia will increase in the future climate. However, after having studied several



Test stand for studying the effects of UV-B on methane emission from plants.

plant generations of genetically different types of barley and oilseed rape in a highly controlled system, our findings indicate that the expected increase in the plant production may not be fulfilled due to the antagonistic effects between climate factors.

### Methane emission from terrestrial plants

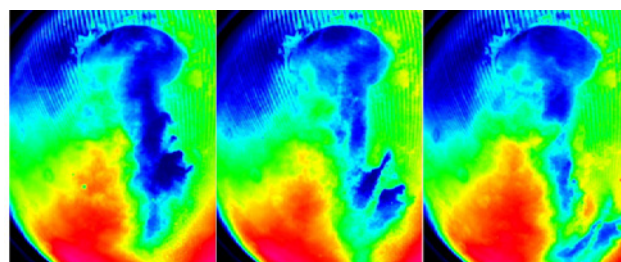
In 2006 it was reported that terrestrial plants may produce and emit methane ( $\text{CH}_4$ ) and that this source may account for 10-40% of all known sources. The phenomenon has subsequently only been confirmed in very few laboratories, including Risø. The arising consensus is two-fold: i) the rates now appear to be two orders of magnitude lower than the originally reported and ii) the main  $\text{CH}_4$  efflux from plant material appears to be nonliving and driven by temperature and UV-irradiation.

In future up-scaling, the temporal component of  $\text{CH}_4$  emission may be rather straightforward as we found  $\text{CH}_4$  emission to be constant through long periods of time. In addition, the spatial component of global  $\text{CH}_4$  emission may also be rather simple as we found that the UV-stimulation is linear and temperature stimulation is exponential. However, it is important to measure  $\text{CH}_4$  efflux from many more species than done so far because of the significant inter-specific variation in the  $\text{CH}_4$  efflux potential. Risø is one of a couple of labs that has observed indications of higher  $\text{CH}_4$  concentration in forest canopies, but it is yet uncertain whether this can be ascribed to plant  $\text{CH}_4$  production.

### Optical methods for characterization of combustion systems

Detailed and accurate measurements of the composition, temperature and pressure of the flue gas in various combustion systems is of high importance for optimizing the combustion and diminishing the exhaust of unwanted components.

Risø has demonstrated mapping of velocities, temperature and gas concentrations in a large 40 MW power plant flame with fast optical methods developed at Risø. It is the first time that accurate data have been obtained in a large scale flame using advanced optical methods. Different fuel combinations have been studied, i.e. straw, wood and coal. Temperature, oxygen and NO concentration are measured with 1 ms measurement time.



Three infrared snap-shot images of 40 MW coal-wood flame with 10 ms between pictures. The flame temperatures are higher in the green-red area than in the region with large concentration of wood particles (blue).

### September 21

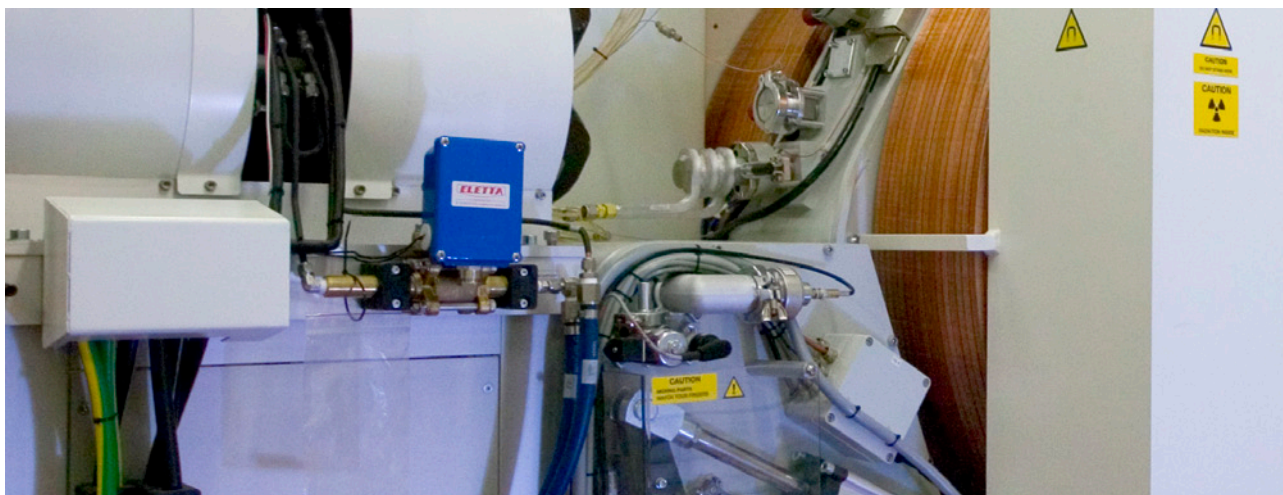
Risø holds "Advanced course on Structural Health Monitoring", 21 – 24 September. The objective is to get the experts prepared for the European and other industries to be able to design and manage structural health of engineering structures in the future.

### November 11

Risø and the Municipality of Roskilde become green partners to strengthen the development of sustainable energy. The joint project comprises establishment of a "Demonstratorium" (test & demonstration) and a sustainable business park.







## Nuclear technologies and ionizing radiation - for the benefit of society

From a historical background within research for the peaceful exploitation of nuclear energy, Risø continues to contribute with research in nuclear technologies and ionizing radiation. Today, focus is on their application in medical sciences, the measurement of radiation dose and in the efficient detection and analysis of radioactive isotopes in environmental samples. In addition, Risø plays a significant role in the national nuclear preparedness programme and radioprotection surveillance. With its activities, Risø continues to expand the opportunities and use of nuclear technologies for the benefit of society.

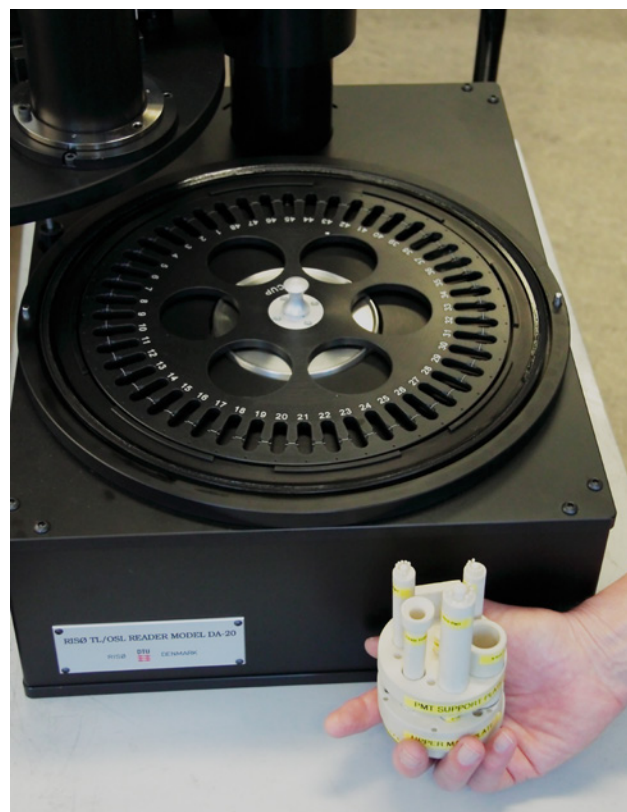
### Risø TL/OSL Reader for 25 years and in 40 countries

The Risø TL/OSL Reader is the world leading instrument for retrospective dosimetry and for geological and archaeological dating. It has been produced since 1984 and has been sold in 40 countries. The instrument is capable of performing automatic measurements of thermoluminescence (TL) and Optically Stimulated Luminescence (OSL) on a large number of samples and can be equipped with specialized attachments for stimulation and detection, allowing for flexible usage of the instrument. The instrument was developed at Risø, and the development continues in close interplay with the radiation physics research on retrospective dosimetry. The Risø TL/OSL Reader is thus a prime example of how research and innovation together may thrive within the framework of the Risø National Laboratory for Sustainable Energy.

### ... and maybe on Mars?

Has there been water on Mars at a time when the temperature would also sustain living organisms? And if so, how long ago? These are two fundamental questions in space research that Risø may be involved in solving. The European Space research Agency (ESA) asked Risø to develop a space model of the Risø TL/OSL Reader, aiming at determining the age of sediments on the surface of Mars. The instrument could play a role in determining whether conditions for life have been present on Mars.

The design phase of the project has been concluded and approved by ESA. Now it remains to build the prototype itself, a so-called elegant breadboard. The instrument is a miniature of the Risø TL/OSL reader in which severe



*In the foreground a 3D printed model of the OSL reader intended for Mars. In the background the "ordinary" commercial Risø TL/OSL reader.*



November 19

19 – 21 November "Green Vision" transforms the town hall square in Copenhagen into an exhibition of creative presentations of green energy technologies. Green Vision is an initiative of DTU-students and is anchored at Risø.

December 3

Bolund Experiment Workshop, 3 - 4 December. 40 companies, universities and research institutions from around the world have participated in a blind comparison of flow models, and the anonymous results are revealed at the workshop.

constraints are placed on the volume and weight. In addition, the system must be able to work in vacuum and under large temperature variations, and naturally, without relying on human intervention for operation or for repair.

### Rapid automated analysis of plutonium in environmental samples

Risø investigates man-made and naturally occurring radioactive substances in environment and food using radiochemical methods and nuclear analytical techniques.

Standard radiochemical methods are particularly demanding in terms of labour and time, especially when used for the analysis of transuranic elements like plutonium, americium and neptunium.

Now Risø has developed an automated method for environmentally relevant concentrations of plutonium in soil, sediment, seaweed and seawater, whereby the procedure can be accomplished in only 2.5 hours. In comparison, when Risø uses the standard radiochemical method for investigation of plutonium contamination from the nuclear bomber crash in 1968 at Thule, Greenland, the chemical separation of plutonium requires 2-3 days.

The new method involves on-line separation of plutonium isotopes using extraction chromatography implemented in a sequential injection network. The method has been applied successfully to analyses of large volumes or amounts of samples, e.g. 100-200 g soil and sediment, 20 g seaweed, and 200 liters of seawater. Also, the method has been tested with certified reference materials and shows good agreement with reference and certified values.



*Risø has several large facilities (see p. 24 -25). One of these is the Hevesy Laboratory, which comprises a 16 MeV proton biomedical cyclotron with a beam-line for production of radioisotopes, and two clean rooms complete with hot-cells. Approved by authorities for the development and production of a portfolio of radiopharmaceuticals.*

Chemical yields for plutonium are high (> 80%), and decontamination factors for interfering elements like uranium, thorium, mercury and lead are all above 104. In addition, reduced amounts of chemicals are required and the risk of cross contamination of samples is minimized.



*Risø has developed an automated method for environmentally relevant concentrations of plutonium in soil, sediment, seaweed and seawater, whereby the procedure can be accomplished in only 2.5 hours.*

Colourbox

#### December 13

Frederick C. Krebs receives the Carlsberg Energy Research Prize 09 in recognition of his research in polymer solar cells. The prize is 100,000 DKK.

#### December 17

The Danish Council for Strategic Research grants a funding of DKK 38 million for the establishment of the Danish Centre for Composite Structures and Materials for Wind Turbines (DCCSM) at Risø.







## Education and training

Risø is deeply involved in education and training, and both university students and participants in Risø's commercial courses come from all over the world, demanding a high quality.

### Growing interest for Master of Science in Engineering (Sustainable Energy)

In 2008 DTU launched a MSc program in Sustainable Energy. The education is offered by Risø in cooperation with a number of departments at DTU. 35 students have started on the master in 2009. In 2008 the figure was 23. The students are mainly from countries within the European Union. During the first semester Risø offers courses on modelling of sustainable energy systems, energy markets resources and policies, and sustainability assessment of energy conversion and use, and these courses attract even more students.

The aim of the education is to educate experts in various energy technologies and energy systems with the focus on sustainability. The education opens up various and different job opportunities within industry, government and research. Professional tasks could be implementation of sustainable energy technologies into existing or new energy systems including modeling and evaluation of impact on ecosystems and society.

### Nordic master programme on "Innovative and Sustainable Energy Engineering"

In 2009 a joint Nordic master programme was established between six Nordic Universities in five Nordic Countries, and its first student enrollment was opened.

Students share time between six top level technical universities, commencing with an intense introductory semester at the Royal Institute of Technology (KTH) in Stockholm focusing on a broad, solid base in energy engineering fundamentals. The second semester or next academic year is spent at another partner university, specialising within key subject areas.

The Technical University of Denmark (DTU) is the Danish university partner, and the training is anchored at Risø.

### Risø offshore wind energy course

Risø offers wind energy courses and training specifically tailored to meet the needs of a particular institution, company or wind energy project, and also offers open courses. In April 2009 the first open technical course on offshore wind energy was offered. The course is intended for wind energy developers, engineers, scientists and others working within the field of offshore wind energy. The course had 12 participants from all over the world, mainly representing the wind energy industry. The course will be repeated annually.

### Forty courses in validation and process control of radiation sterilization

Since 1993 Risø has offered post-graduate courses in validation and process control in radiation sterilization, and in 2009 the 40th course was completed.

The courses are aimed both at industrial users of radiation sterilization of e.g. medical equipment, and at authorities. Since the beginning the courses have had a large number of both Danish and international participants, and more than 100 different companies have participated in the course.

### Increased number of PhD-students at Risø

Risø gives a high priority to providing PhD students the time and space for in-depth study and as much support as possible. The PhD students are part of daily life at Risø, and his or her research is integrated with the other research being conducted at Risø, and thus he or she makes a difference as a researcher at Risø.

In 2009 the number of PhD-students increased to more than 80 students (Full Time Equivalents).







Colourbox

## Innovation and business

Risø has a long track record of cooperation with industries, innovation activities and the supply of highly specialized products and services on commercial terms. Through a dedicated innovation activity, Risø has created a systematic process for the transformation of its knowledge into concrete business ideas:

- Building on our technological advancements, we identify and initiate business start-ups
- In collaboration with industrial partners we address and provide solutions to technological challenges that prevent the creation of new products
- We undertake specialized assignments on commercial terms
- We provide specific products, where we have a special expertise.

It is Risø's mission to contribute to research, development and international exploitation of sustainable energy technologies and strengthen economic development in Denmark, and Risø thus takes it very serious that our research must contribute to growth and economic development in Denmark. Our work within the cooperation agreement with Region Zealand, and the launch of a new initiative called Copenhagen Cleantech Cluster, are examples of this.

### Cooperation with Region Zealand (Denmark)

Since 2007 Risø has had a cooperation agreement with the Region Zealand with the goal for Risø to contribute to growth in Region Zealand. Within this agreement Risø has had dialogue with nearly 200 companies, and more than 10 matchmaking events/networks with groups of companies have taken place as well as events for individual companies. Furthermore, more than 40 innovation projects are being developed and several of these have reached a phase where they are expected to be spun out in existing or new start-up companies.

One of the innovation projects is a cooperation between Risø, the company Sahva and a DTU-student and aims at development of a *bandage that makes life easier for people with hip replacements*. The idea was generated at a workshop at Risø with participants from hospitals, scientists, a company, an investor and a patient. Next step is to test the prototype at hospitals in Zealand (Holbæk, Næstved and Køge) and after adjustment to launch it as a commercial product.

Another example of an innovation project is about *controllable rubber trailing edge flap CRTEF* to reduce loads on

wind turbine blades. The trailing edge of wind turbine blades can be manufactured in an elastic material that makes it possible to control the shape of the trailing edge. Risø holds a patent application for this basic technique, and by means of gap-funding provided by the Danish Ministry of Science, Technology and Innovation and by the Region Zealand it has been possible to develop the ideas into a prototype. The prototype was tested among other things with respect to deflection, and the functional principle was fully confirmed. In December 2009 a further step in the development process was taken when a 2m long flap section was successfully tested in the Velux wind tunnel in Jutland, demonstrating the aerodynamic efficiency of the flap to regulate loads. The future plans are now to work together with industrial partners to develop a prototype that can be tested on a full scale MW turbine.

### Copenhagen Cleantech Cluster

On 9th September 2009 a new initiative was launched in which Risø plays a central role. Risø joined forces with Copenhagen Capacity, Scion DTU, University of Copenhagen, The Confederation of Danish Industry and 20 companies and other parties in initiating Copenhagen Cleantech Cluster (CCC).

CCC is intended to strengthen business development in green technologies, and it is the vision that the Danish cluster will be one of the leading clusters in the world, where it will differentiate itself by working across industries and value chains. DTU's technical and scientific skills are central to the cluster and Risø DTU will act as the entrance to other relevant research competences at DTU.





## Research, development and testing facilities

Energy research and development includes a number of tasks that can only be achieved through the use of large research facilities, and Risø has a number of such facilities.

Also, Risø has bilateral agreements at institutional level and through a qualified staff access to and experience with synchrotrons, reactors and fusion experiment facilities in Europe and the USA, e.g. European Synchrotron Radiation Facility (ESRF), Paul Scherrer Institut (PSI) and Hamburger Synchrotronstrahlungslabor (HASYLAB).

Below is listed some of Risø's research, development and testing facilities.

<b>Experimental Research Facility for Blade Structure</b>	<i>Experimental research facility for full-scale testing of wind turbine blades. The facility will take a blade up to 30-40 metres long and apply combined loading during tests.</i>
<b>Høvsøre Test Station for Large Wind Turbines</b>	<i>Megawatt-size wind turbines are tested, and research projects are carried out on boundary layer meteorology and lidar wind measurements.</i>
<b>Risø Research Facility for Wind Turbines</b>	<i>Six test stands for wind turbines up to 500 kW. For every stand there is a mast equipped to monitor e.g. wind direction, temperature and pressure for the calculation of power. Used for a variety of experiments and research projects, including blade design, and by DTU for educational purposes.</i>
<b>Facilities for electrochemical testing of fuel cells and electrolytic cells</b>	<i>Test stations for electrochemical testing for short-term, long-term and accelerated testing in controlled environments.</i>
<b>Pre-pilot plant for advanced ceramic process technology</b>	<i>Ceramic manufacturing technologies for the fabrication of multilayer electrochemical cells and in particular solid oxide fuel cells. This includes colloidal, shaping and sintering techniques and characterization.</i>
<b>MaxiFuel pilot plant</b>	<i>Co-production of bioethanol, biogas and hydrogen is being studied.</i>
<b>Thermal gasification experimental facilities</b>	<i>Laboratory and pilot plant for thermal gasification of biomass (wood, organic waste etc.).</i>
<b>Polymer solar cell processing facilities</b>	<i>Glove box process line for fabricating and testing laboratory scale solar cells in controlled atmosphere. Reel-to-Reel (R2R) coating, screen printing and lamination facilities for all-printed polymer solar cells.</i>





<b>SYSLAB</b> Research facility for intelligent energy systems	<i>Flexible platform for research in advanced control systems and concepts, power system communication and component technologies for distributed power systems.</i>
<b>Brandbjerg (CLIMAITE)</b> Experimental research site to model the Danish ecosystem for the year 2075	<i>Established by CLIMAITE, a Danish research centre to investigate how climatic changes will affect biological processes and natural ecosystems. Center leader: Risø.</i>
<b>RERAF</b> Risø Environmental Risk Assessment Facility	<i>Plant growth facility belonging to a new generation of phytotrons. Experiments can be carried out under fully controlled conditions.</i>
<b>Hevesy Laboratory</b> Radiochemical and radiopharmaceutical facility	<i>Comprises a 16 MeV proton biomedical cyclotron with a beam-line for production of radioisotopes, and two clean rooms complete with hot-cells. Approved by authorities for the development and production of a portfolio of radiopharmaceuticals.</i>
<b>Risø High Dose Reference Laboratory</b>	<i>National Metrology Institute for industrial dosimetry with irradiation facilities for traceable calibration of dosimeters in the dose range 100 Gy - 100 kGy. The facilities comprise 3 cobalt-60 gammacells and an electron accelerator with energy range 80 - 125 keV.</i>
<b>Risø OSL Laboratory</b> Facility for research into the luminescence behavior of natural minerals	<i>Used for all forms of retrospective dosimetry including geological and archaeological dating and accident dosimetry. Includes 21 state of the art automated TL/OSL readers, high resolution gamma spectrometry and sample preparation facilities. The facility is run in close cooperation between Risø and Aarhus University.</i>
<b>Electron microscopes</b>	<i>Electron microscopes comprising different types of transmission, scanning and scanning probe microscopes. Inclusive, the first of its kind Hysitron stage for in-situ mechanical testing in the High Resolution Electron Microscope (HREM).</i>
<b>Laboratory for mechanical testing</b>	<i>Equipped for both uniaxial and multiaxial testing. Accredited by the Danish Accreditation DANAK.</i>
<b>Thermal analysis laboratory</b>	<i>In-situ studies of material properties as they change with temperature, including thermogravimetry, dilatometry, calorimetry and conductivity measurements in the total range of 1700°C, under inert, oxidizing or reducing atmospheres.</i>
<b>Thermometry laboratory</b>	<i>Accredited "in situ" measurements in the range -196 to 1600 K, especially demanding temperature measurements and calibrations in large power plants and incinerators.</i>
<b>X-ray scattering facility</b>	<i>In-situ studies of the structural changes that take place in advanced energy materials.</i>

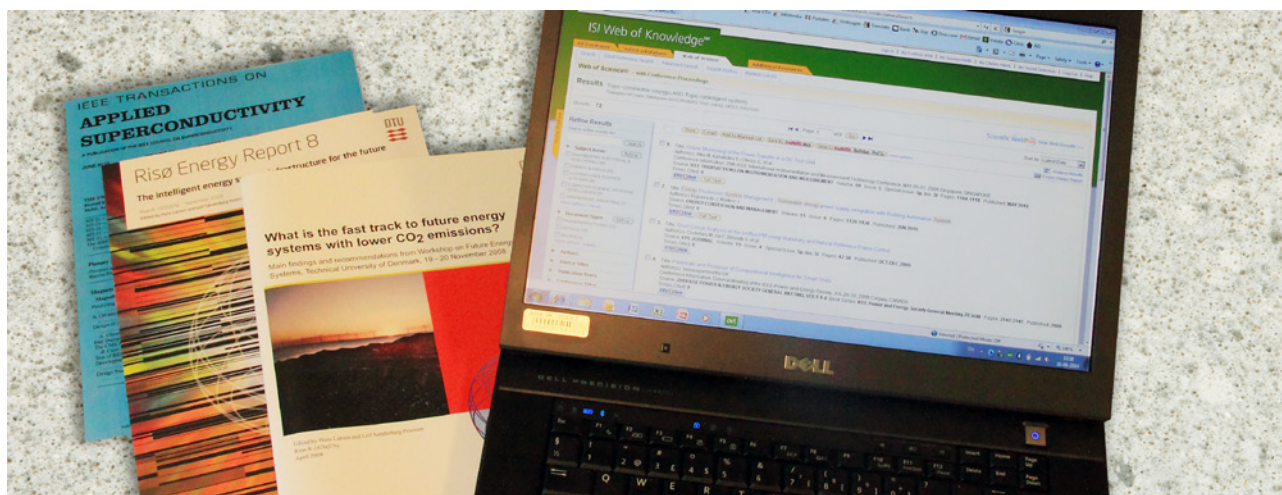


Brandbjerg (CLIMAITE) is an experimental research site to model the Danish ecosystem for the year 2075.



A large solar panel is integrated in SYSLAB, Risø's research facility for intelligent energy systems.





## Publications

Our research results in extensive publication activities through articles in international refereed journals, research reports and other publications. Publications are part of the basis for transferring knowledge and technology to Risø's stakeholders in the political system, industry and research.

Publications 2009	Total number
Scientific articles with refereee	350
Books/contributions to books	81
Scientific reports	69
Ph.D. Thesis + Dr. Thesis	12 + 1
Contributions to conference proceedings	87
Other conference and meeting contributions (published abstracts/unpubl. abstracts)	403
Publications for a broader readership	31

### Citation impact based on one publication year

Publication year	Average number of citations
2006 - 2009	8,66
2005 - 2008	8,33
2004 - 2007	8,48
2003 - 2006	8,46
2002 - 2005	7,00
2001 - 2004	8,28
2000 - 2003	7,82

*The table shows the average number of citations for articles published in the first year of a four-year period. E.g. for the period 2006-2009: Average number of citations of articles published in 2006 and cited in 2006-2009. The table is based on Web of Science (Thomson Scientific).*

### The intelligent energy system infrastructure for the future (Risø Energy Report 8)

The report presents the need for the development of a highly flexible and intelligent energy system infrastructure which facilitates substantial higher amounts of renewable energy than today's energy system. A generic approach is presented for future infrastructure issues on local, regional and global scale with focus on the energy system itself.

Risø Energy Report Series was established in 2002. The yearly reports deal with global, regional and national perspectives on current and future energy issues. Each report is based on internationally recognised scientific material, it is fully referenced and it is refereed by an independent panel of international experts.

### Energy solutions for CO<sub>2</sub> emission peak and subsequent decline (Risø-R-1712)

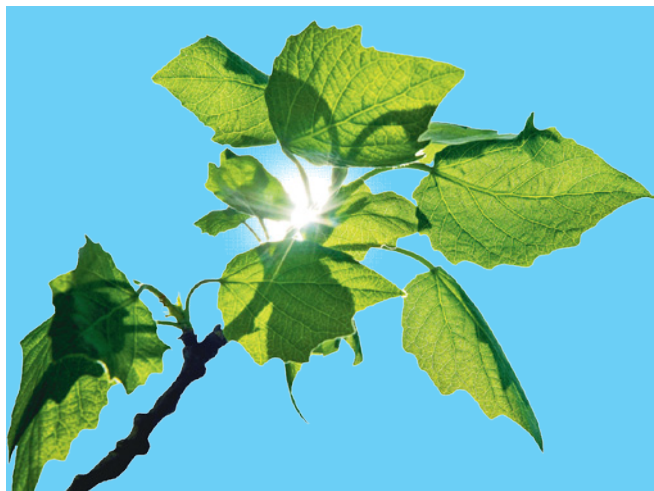
This was the subject for the Risø International Energy Conference 2009, held at Risø DTU 14-16 September 2009.

One of the major conclusions from the conference was that after the year 2050 it may be necessary to knock the global CO<sub>2</sub> emissions down below 0, so the world community actually must reduce the atmospheric CO<sub>2</sub> content. In the time up to 2050 the conference participants felt that there should be 80% cut in CO<sub>2</sub> emissions compared with today.

The conference is held every second year, and the proceedings are published in the Risø-R-report series, a report series established in 1958.





**Mission:**

Risø DTU contributes to research, development and international exploitation of sustainable energy technologies, and strengthens economic development in Denmark.

**Vision:**

Risø DTU is one of Europe's leading research laboratories in sustainable energy and is a significant player in nuclear technologies. Risø creates pioneering research results and contributes actively to their exploitation, both in close dialogue with the wider society.

**Management**

Director *Henrik Bindslev*

Head of Biosystems Division *Kim Pilegaard*

Head of Fuel Cells & Solid State Chemistry Division *Søren Linderøth*

Head of Intelligent Energy Systems Programme *Anders Troi\**

Head of Materials Division *Dorte Juul Jensen*

Head of Plasma Physics and Technology Programme *Jens Juul Rasmussen*

Head of Radiation Research Division *Lars Martiny*

Head of Solar Energy Programme *Peter Sommer-Larsen*

Head of Systems Analysis Division *Hans Larsen*

Head of Wind Energy Division *Peter Hauge Madsen*

Head of Administration

*Lisbeth Grønberg*

Head of Information Service

*Birgit Pedersen*

Head of IT Service

*Michael Rasmussen*

**Personnel 2009 - FTE**

Total number of employees - Full Time Equivalents 639

*Of this*

Scientists (VIP) 266

Ph.d students 83

Other staff (TAP) 290

*Additionally, a number of visiting scientists and master students.*

**Operating statements 2009 (DKK mill.)**

Total income 622

*Of this*

Basis appropriation 306

Programme activities 202

Market controlled activities 114

Total expenditure 620

*Of this*

Salaries 317

Operating expenditures 273

Depreciation 30

*\*From 1 February 2010*



Risø DTU is the National Laboratory for Sustainable Energy. Our research focuses on development of energy technologies and systems with minimal effect on climate, and contributes to innovation, education and policy. Risø has large experimental facilities and interdisciplinary research environments, and includes the national centre for nuclear technologies.

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